Space Technology Mission Directorate
Game Changing Development Program
2017 1st Quarter Review

National Aeronautics and
Space Administration

Composite Technology for Exploration

Presented By: John Fikes

January 2017

TECHNOLOGY DRIVES EXPLORATION

Project Manager 1st Quarter Assessment

Technology	Performance				Comments
	T	C	S	P	
Composite Technology for Exploration					CTE Project Team has been formulated. Project plan containing task definition, baseline schedule and milestones has been reviewed by the Program. MSFC and SLS management review and signatures in work. Composite material requalification is in-work. Composite joint design analysis tools study underway.

Composite Technology for Exploration Overview

The CTE Project will develop and demonstrate critical composites technologies with a focus on joints that utilize NASA expertise and capabilities. The project will advance composite technologies providing lightweight structures to support future NASA exploration missions. The CTE project will demonstrate weight-saving, performance-enhancing bonded joint technology for Space Launch System (SLS)-scale composite hardware.

Integration with other projects/programs and partnerships

- HEOMD – SLS SPIE Payload Attach Fitting (PAF) composite design risk reduction

Technology Infusion Plan:

- Composite Bonded Joint Design and Analysis
- HEOMD – SLS
- Block upgrades

Key Personnel:

Program Element Manager: Michael Meador

Project Manager: John Fikes

Lead Center: MSFC

Supporting Centers: GRC, GSFC, LaRC

NASA NPR: 7120.8

Guided or Competed: Guided

Type of Technology: Push

Key Facts:

GCD Theme: Lightweight Materials and Advanced Manufacturing

Execution Status: Year 1 of 3

Technology Start Date: FY2017

Technology End Date: FY2019

Technology TRL Start: 3

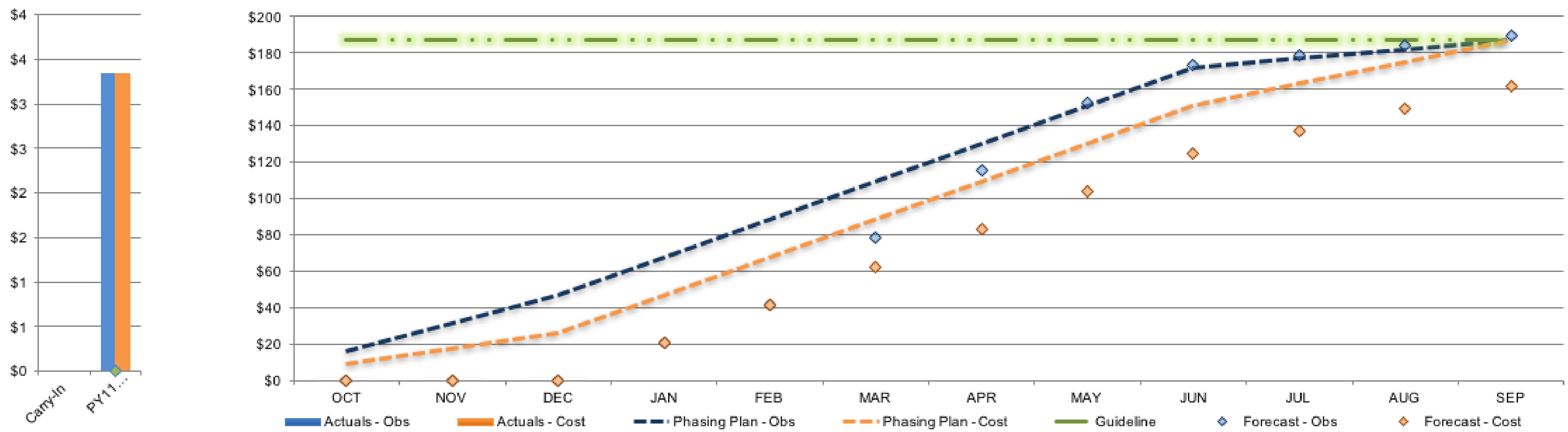
Technology TRL End: 5

Technology Current TRL: 3

Technology Lifecycle Phase: Phase A

Resources: Non-Labor Obligations and Cost

FY 2017 Non-Labor Financial Status



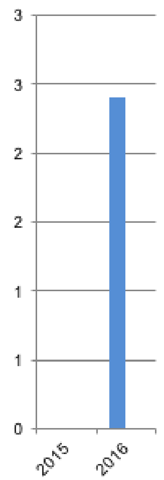
	Cum ($K)	Carry-In	PY11-16 Funds	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Carry Out
	Guideline		0.0	187.5	187.5	187.5	187.5	187.5	187.5	187.5	187.5	187.5	187.5	187.5	187.5	
Obs	Phasing Plan (RLP)			15.6	31.1	46.7	67.5	88.3	109.1	129.9	150.7	171.5	176.9	182.2	187.5	(3.3)
Obs	Actuals	0.0	3.3		0.0	0.0										
Obs	Forecast				-	-	20.8	41.6	78.6	115.6	152.6	173.4	178.8	184.1	189.4	(5.2)
Cost	Phasing Plan (RLP)			8.6	17.2	25.8	46.6	67.5	88.3	109.1	129.9	150.7	163.0	175.2	187.5	3.3
Cost	Actuals	0.0	3.3		0.0	0.0										
Cost	Forecast				-	-	20.8	41.6	62.4	83.2	104.1	124.9	137.1	149.4	161.7	31.1

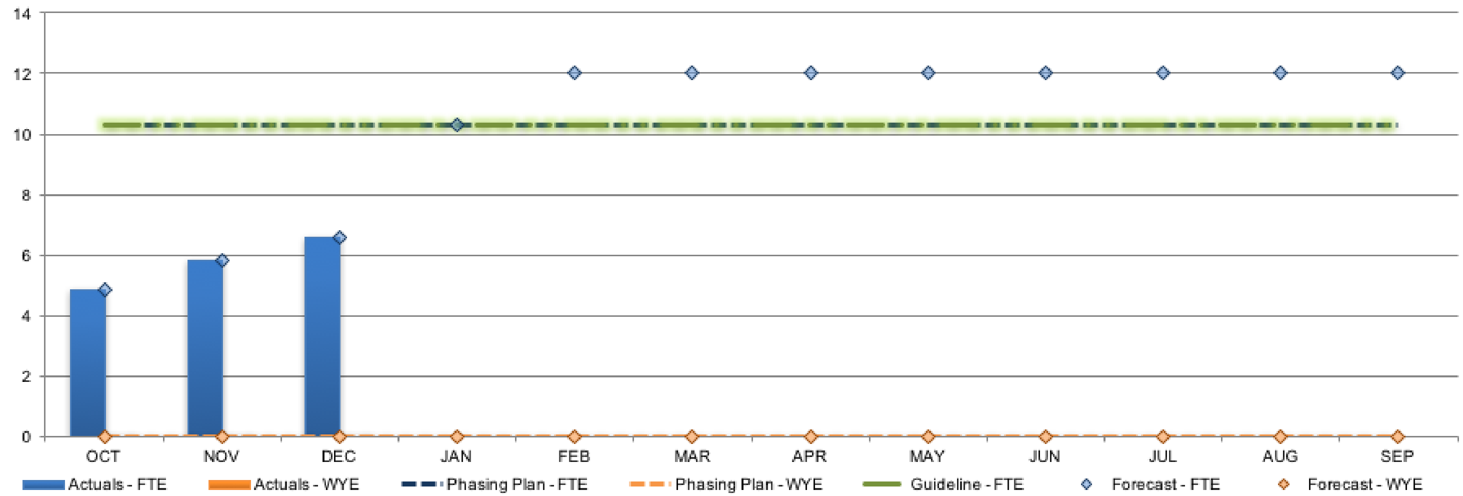
Note: Carry-In is the unobligated/uncosted portion of PY11-16 funding end of FY16

	YTD Status		Explanation required for YTD Variance in excess of 5% from Phasing Plan (shaded red)
'17 Obs	Phasing	$ 47	Currently operating under CR thru April 2017. Backpack payments will be made in 2nd quarter.
	Actuals	$ -	
	Variance	$ (47)	
'17 Cost	Phasing	$ 26	Currently operating under CR thru April 2017. Backpack payments will be made in 2nd quarter and costed by the end of FY17.
	Actuals	$ -	
	Variance	$ (26)	

Resources: Total Project Workforce FTEs/WYEs

FY 2017 Workforce Status

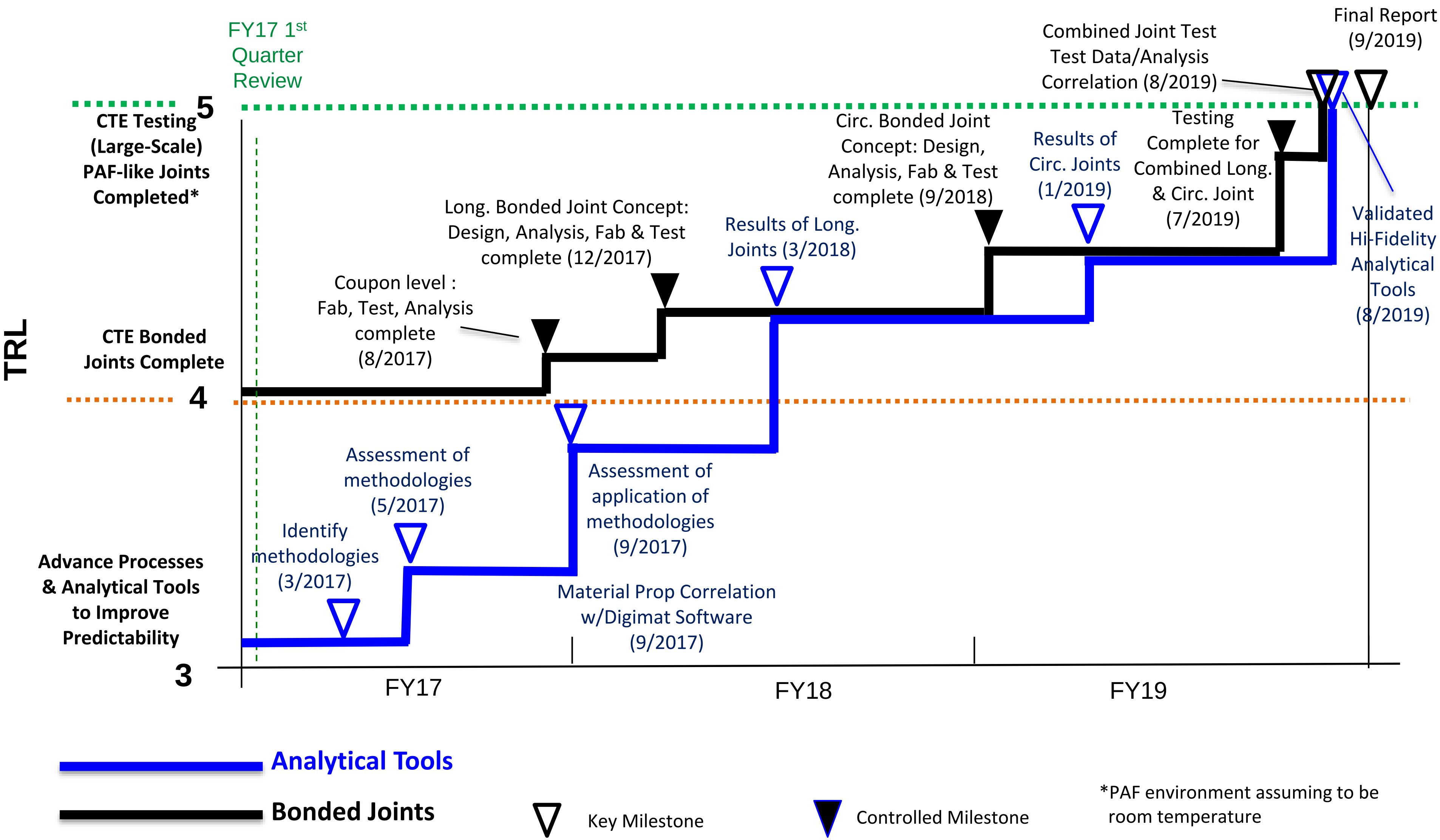




	Incremental	2015	2016	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	2017 Avg
FTE	Guideline			10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3
	Phasing Plan (RLP)			10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3
	Actuals	0	2.4	4.9	5.8	6.6										5.7
	Forecast			4.9	5.8	6.6	10.3	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	10.3
WYE	Phasing Plan (RLP)															0.0
	Actuals	0.0	0.0													
	Forecast															

	YTD Status		Explanation required for YTD Variance in excess of 5% from Phasing Plan (shaded red)
'17 FTE	Phasing	10.3	Currently under run of labor due to project task formulation and getting started. FTE's have been ramping up and allocations are projected to be utilized by end of FY.
	Actuals	5.7	
	Variance	(4.6)	
'17 WYE	Phasing	N/A	
	Actuals	N/A	
	Variance	N/A	

CTE TRL/KPP Assessment



*PAF environment assuming to be room temperature

CTE Performance

Key Performance Parameters				
Performance Parameter	State of the Art	Threshold Value	Project Goal	Estimated Current Value
1. Reduce part count associated with joints in primary load path for 8.4m diameter scale composite structures (example: reduction from 500 parts in an all-metal bolted joint to much fewer parts in an all-bonded joint)	100% metal/bolted joint	25% reduction in part count	50% reduction in part count	
2. Reduce weight associated with joints in primary load path for 8.4m diameter scale composite structures (example: reduction from 3 lb/ft joint length to much lower weight per linear foot bondline length)	Metal/bolted joint	15% reduction from metal or bolted joint	25% reduction from metal or bolted joint	
3. Reduced discontinuity factor of safety for joints in primary load path for PAF composite structure (Discontinuity Factor of Safety = $\varphi * 2.0$, where φ is a risk reduction factor based on analyses and test)	**2.0** (current requirement)	**1.8** (tailored approach)	**1.5** (tailored approach)	

CTE Milestones and Forward Plans

Composite Technology for Exploration Project (CTE)		
Milestones	**Baseline Date**	**Milestone Type**
FY17		
OoA Material down select & Procurement	May 26, 2017	Key Milestone
Report- Material Equivalency Testing & Analysis of IM7/8552-1	July 31, 2017	Key Milestone
Complete Fabrication, Testing & Data Analysis for Coupon Level Material Development	August 4, 2017	Controlled Milestone
Report- Correlation of Digimat Computational Models with Material Property Test Data	September 26, 2017	Key Milestone
Report- Correlation of Digimat Computational Models with Material Property Test Data	February 8, 2017	Key Milestone
Report- Assess, Apply & Compare Bonded Joint Strength Prediction Methodologies	September 29,2017	Key Milestone
Down select of Longitudinal Joint Design Concept for SLS Specific application (i.e. EUS, PAF)	May 8, 2017	Controlled Milestone
Report- Application & Implementation of New Manufacturing Process Control and NDE Technologies	September 29,2017	Key Milestone
Report- Shell Buckling Knockdown Factor (SBKF) Sensitivity Analysis	September 29,2017	Key Milestone
FY18		
Complete Design, Analysis, Fabrication & Testing of down selected Longitudinal Bonded Joint Concept	December 19, 2017	Controlled Milestone
Report- Results of Longitudinal Joint Design, Manufacturing, Analysis & Testing	March 13, 2018	Key Milestone
Complete Circumferential Bonded Joint Concept Design, Analysis, Manufacturing & Testing	September 28, 2018	Controlled Milestone
Complete Design, Analysis, Fabrication & Testing of Large-Scale Longitudinal Bonded Joint Concept	September 28, 2018	Controlled Milestone
Complete Design & Analysis of Combined Joint Test Articles and Test Fixtures	September 28, 2018	Key Milestone
FY19		
Report- Results of Validated Hi-Fidelity Analytical Tools for Predicting Failure & Residual Strength of Selected Composite Joints	July 5, 2019	Controlled Milestone
Report- Results of Circumferential Joint Manufacturing, Analysis & Testing	January 14, 2019	Key Milestone
Complete Combined Longitudinal & Circumferential Joint Manufacturing & Testing	July 5, 2019	Controlled Milestone
Combined Longitudinal and Circumferential Joint Testing Complete	August 2, 2019	Key Milestone
Final Report Complete	September 27, 2019	Key Milestone

CTE Schedule

Composite Technology for Exploration Project

FY16: S O N D | FY17: J F M A M J J A S O N D | FY18: J F M A M J J A S O N D | FY19: J F M A M J J A S O N

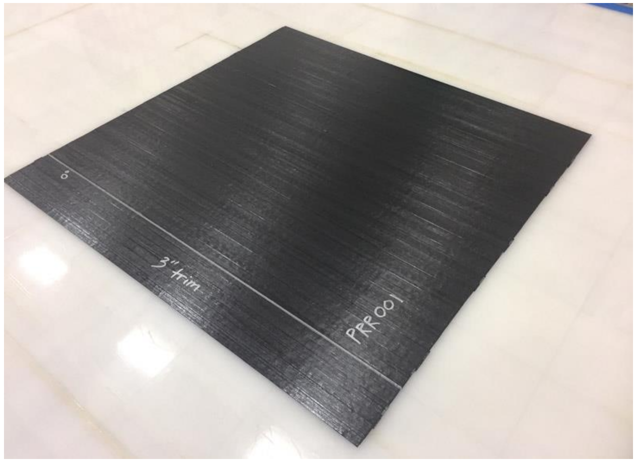
#	Task	Start	End
1	Select and Procure Out of Autoclave Joint Materials	11/28	6/26
2	Complete Material Equivalency Testing and Analysis of IM7/8552-1	11/28	7/31
3	**Fabricate and Test Joint Material Test Coupons**	2/28	**8/4**
4	Correlate Material Properties with Digimat Software	12/6	9/26
5	Evaluate Prior Composite Joint Studies and Activities	12/20	2/8
6	Evaluate Bonded Joint Strength (Failure) Prediction Methodologies	12/20	9/29
7	**Design and Analyze Longitudinal and Circumferential Baseline Metallic and Composite Joints for SLS-Specific Applications**	1/31	**5/8**
8	**Design, Analyze, Fabricate, and Test Longitudinal Bonded Joint Concepts to Validate Composite Joint Design and Strength Prediction Methodologies**	5/8	**12/19**
9	Implement New Technologies in Manufacturing Process Control and Nondestructive Evaluation (NDE)	11/28	9/29
10	Support the Shell Buckling Knockdown Factor (SBKF) Project	1/31	9/29
11	Report Results from Longitudinal Joint Development Studies	12/20	3/13
12	**Design, Analyze, Fabricate, and Test Circumferential Bonded Joint**	10/2	**9/28**
13	**Validate Failure Theories, Damage Prediction, and Simulation Methodologies for Selected Composite Joints**	10/2	**7/5**
14	**Design, Analyze, Fabricate, and Test Large Longitudinal Joint Panel to Support Bond Failure Criteria and Strength Verification**	10/2	**9/28**
15	Design and Analyze Combined Joint (Longitudinal and Circumferential) Test Specimens and Test Fixtures for SLS-Specific Applications	6/25	9/28
16	Report Results from Circumferential Joint Development Studies	10/15	1/14
17	**Fabricate and Test Combined Longitudinal and Circumferential Bonded Joint Test Articles**	10/29	**7/5**
18	Combined Longitudinal and Circumferentential Joint Testing Complete		8/2
19	Final Report Complete		9/27

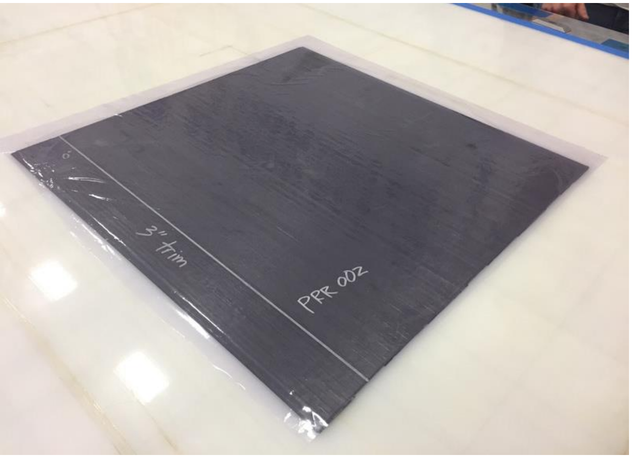
CTE Technical Accomplishments and Technical Challenges

- **Project Plan status – GCD Program review complete with all actions and updates complete. MSFC and SLS management signatures in work.**
- **Re-certification work has begun on material that was left over from the CEUS project (~ 2,000 lb at MSFC and 200 lb at LaRC).**
  - Material is now past its shelf life, but has been in the freezer and is expected to be acceptable; will be re-certified through appropriate mechanical and chemical tests.
  - Composite panel production for mechanical testing has begun at MSFC. Panels are being fabricated according to the same layups and cure cycle originally used by Hexcel.
- **Materials lead (GRC) is in the process of getting quotes for materials and testing services.**
  - Out-of-Autoclave Prepreg – quote received
  - Joint Pre-forms
  - Mechanical testing
- **Design and Analyses team (co-led out of LaRC and GSFC) had a kickoff meeting and collected relevant prior joints analyses work for review.**
  - Analyses/Computational Materials
  - Process developed to make 8552-1 resin coupons void free

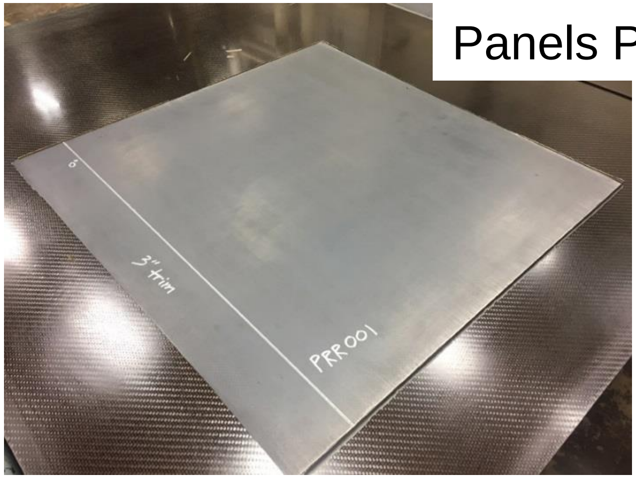
CTE Technical Accomplishments

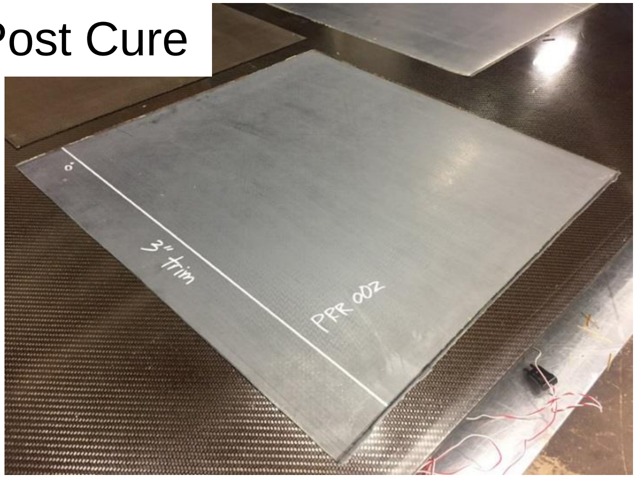
Panel Fabrication for Material Requalification (MSFC)





Panels Post Cure

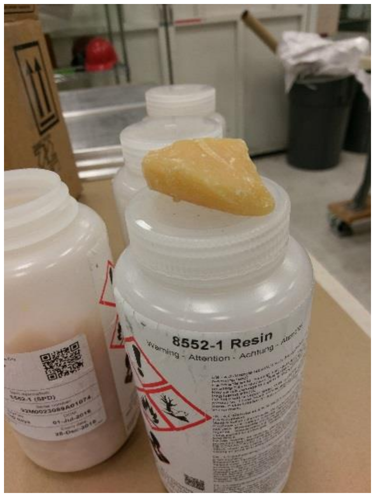




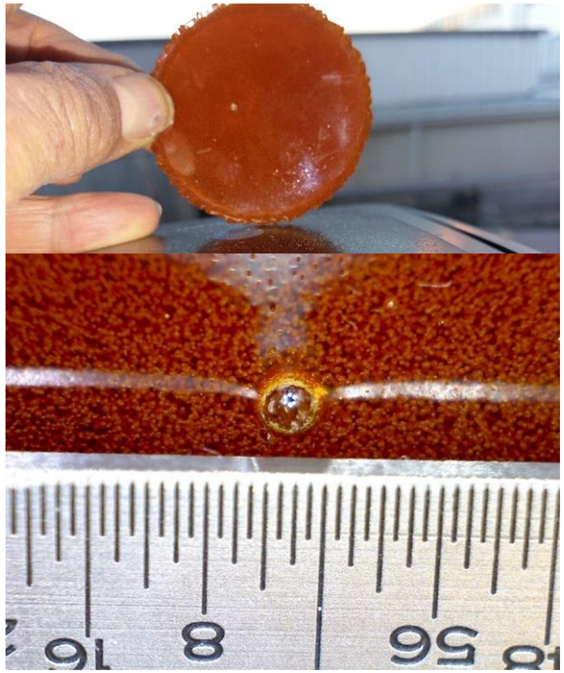
- Ply lay-up and cure cycle details used to generate certification data were provided by Hexcel.
- Specimens will be tested according to the same test standards used by Hexcel to assess material performance for continued use.
- A $[0]_6$ lamina panel has been laid up for lamina tension testing.
- A $[0]_{12}$ lamina panel has been laid up for lamina compression and short beam shear testing.

CTE Technical Accomplishments

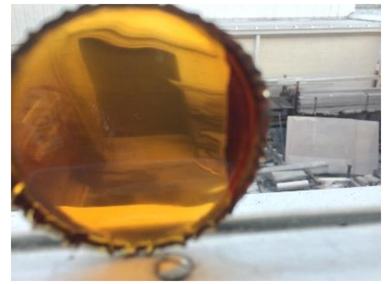
Computational Materials Work (GSFC)



Hexcel 8552-1 Neat Resin



Large and small voids present after curing with heat and under a vacuum bag

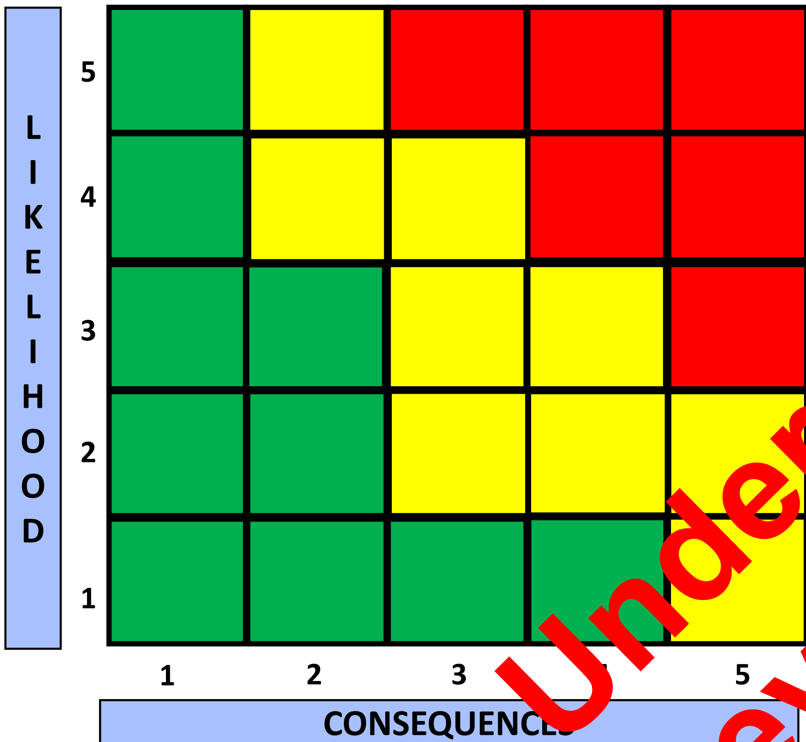


Heated vacuum process established to extract gases

Process developed to make 8552-1 resin coupons void free

- Panels made with this process are for resin mechanical characterization tests
- Digimat software will use fiber and resin constituent properties to establish composite laminate design allowables.

CTE Risk Summary



Risk ID Trend	Approach/ Affinity	Risk Title
⇨ ID#	M/T	

Under Development

Criticality
- High
- Med
- Low

L x C Trend
- ⇩ Decreasing (Improving)
- ⇧ Increasing (Worsening)
- ⇨ Unchanged
- ☐ New Since Last Period

Approach
- M - Mitigate
- W - Watch
- A - Accept
- R - Research

Affinity: T-Technical C-Cost Sc-Schedule

\- Sa-Safety

Summary and Significant Challenges

Project Summary Performance

Project	Summary Performance				Rationale
	Technical	Cost	Schedule	Programmatic	
Quarter 1					CTE Project is stood up. Project Plan is being finalized through management. Design/Analysis Team and Materials/Manufacturing Team are working to defined tasks and maintaining schedule.
Quarter 2					
Quarter 3					
Quarter 4					

Back Up Charts

<These charts feed Quarterly Reporting. All charts are required. >

Technology Name

Risk Title (*short risk title*) – Risk Owners name

Risk ID #

No. unique to this risk- stays with risk even when closed/retired.

Trend

High

Criticality

Current L/C

5x5

Affinity Group

(could be more than one) Technical, Cost, Schedule, Performance

Planned Closure

mm/dd/yyyy

Open Date

mm/dd/yyyy

Risk Statement : **Approach: (choose one) Mitigate, Watch, Accept, Research, Transfer, Exploit, Share, Enhance**

Risk Statement in the format "Given that (state the fact)…there is a possibility (state the concern)…resulting in (state the consequence..)"

Context

Info and background NOT in the Risk Statement. Captures the what, when, where, why, and how of the risk, specifically: What do we need to know to fully understand the risk? What are the relevant and related circumstances, contributing factors, and related issues?

Status

mm/yyyy of update. Information regarding current status. Revisited monthly. Current month on top. OK to eliminate status updates more than three months old to keep this page from getting too large.

(Note: The Schedule UID is the unique id no of the mitigation step in your schedule if appropriate.

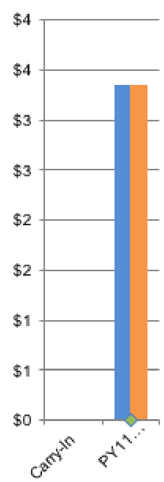
Dollars to implement are not extra approved $ from the Program Office but $ set aside as part of project budget to mitigate.)

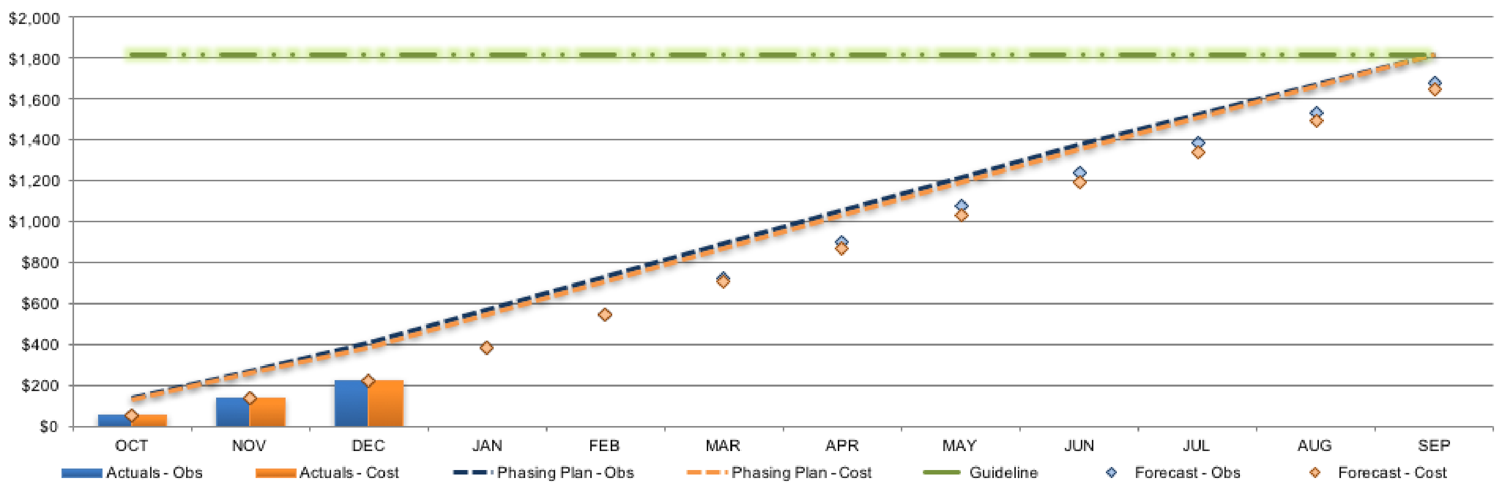
Mitigation Steps	Dollars to implement	Trigger/ Start date	Schedule UID	Completion Date	Resulting L/C
1					

Continue on second page if required

Resources: Total Obligations and Cost

FY 2017 Financial Status





	Cum ($K)	Carry-In	PY11-16 Funds	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Carry Out
	Guideline		0.0	1,815.7	1,815.7	1,815.7	1,815.7	1,815.7	1,815.7	1,815.7	1,815.7	1,815.7	1,815.7	1,815.7	1,815.7	
Obs	Phasing Plan (RLP)			135.0	269.9	404.9	566.8	728.7	890.6	1,052.5	1,214.5	1,376.4	1,522.8	1,669.2	1,815.7	(3.3)
Obs	Actuals	0.0	3.3	51.9	137.4	218.6										
Obs	Forecast			51.9	137.4	218.6	380.5	542.4	720.5	898.6	1,076.8	1,238.7	1,385.1	1,531.5	1,678.0	134.4
Cost	Phasing Plan (RLP)			128.0	256.0	384.0	546.0	707.9	869.8	1,031.7	1,193.6	1,355.5	1,508.9	1,662.3	1,815.7	3.3
Cost	Actuals	0.0	3.3	51.9	137.4	218.6										
Cost	Forecast			51.9	137.4	218.6	380.5	542.4	704.4	866.3	1,028.2	1,190.1	1,343.5	1,496.9	1,650.2	31.1

Note: Carry-In is the unobligated/uncosted portion of PY11-16 funding end of FY16

	YTD Status			Explanation required for YTD Variance in excess of 5% from Phasing Plan (shaded red)
'17 Obs	Phasing	$	405	Currently operating under CR thru April 2017. Backpack payments will be made in 2nd quarter. Labor under run ramping up.
	Actuals	$	219	
	Variance	$	(186)	
'17 Cost	Phasing	$	384	Currently operating under CR thru April 2017. Backpack payments will be made in 2nd quarter. Labor under run ramping up.
	Actuals	$	219	
	Variance	$	(165)	

Excel File: STMD and GCD Data Request

- **Milestone Completion and Burndown**
- **Technology Transfer or Infusion**
- **EPO: Activities, Conferences, and Students**
- **Economic Development**

- **Post Excel File to the following link on NX: https://nx.larc.nasa.gov/dsweb/View/Collection-95546**

Use Excel file sent with the template and located on NX

Composite Technologies for Exploration

STATUS QUO

- Joints are heavy and not optimized. Majority of joints are mechanically fastened, creating the opportunity for self-induced damage from the joining process.
- Analytical tools and techniques do not accurately predict composite failure modes.
- Inspection techniques and tools are time consuming and need improvement in certain configurations (bondline, core).
- Limited model-based virtual materials, design and manufacturing capabilities lead to extensive development cycles.

NEW INSIGHTS

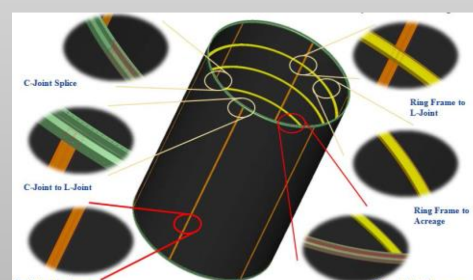
- Recent USA RFI responses from industry indicated bonded joints as being a key enabling technology for the development of efficient sandwich composite launch vehicle structures.
- To maximize performance potential for composite structures there needs to be improved analytical techniques and tools.
- Advances in several technology areas will enable significant improvements in performance and cost of SLS composite structures.
- Development and assessment of light-weight, stiffness-neutral joint concepts.
- Development and implementation of improved process control and NDE processes.
- Development and validation of high-fidelity analysis tools for predicting failure and residual strength of said bonded joints.

PROBLEM / NEED BEING ADDRESSED

NASA lacks experience with large-scale (8.4m diameter) composite joints; joining of composites has been called the *Achilles heel* of composite structures.

TASK DESCRIPTION/APPROACH

- Revisit past composite studies and activities dealing with composite joints, analysis tools and inspection. Also investigate industry standards in these areas.
- Design, fabricate, and test a suite of light-weight stiffness-neutral bonded joint concepts for SLS-specific applications.
  - Test coupons (small panels) and large-scale cylindrical panels to assess the performance of selected jointing concepts subjected to relevant loading conditions, with and without impact damage, manufacturing flaws and repairs.
- Develop design values and guidelines for selected joints for SLS-specific applications.
- Additional panels with design features will be analyzed, fabricated, and tested.
  - Design features include a large opening representing a door and a small opening representing a vent, both of which are non-load bearing.
  - One large segment panel test and one smaller curved panel test will be conducted using representative compression loads.
- Develop and validate high-fidelity analysis tools and standards for the prediction of failure and residual strength of selected joints.
  - Design and execute tests to verify predicted strain and deformation response in bonded joints.
  - Validated analysis tools may be used as virtual tests to reduce reliance on testing necessary for design justification and certification → reduce design cycle time and cost.



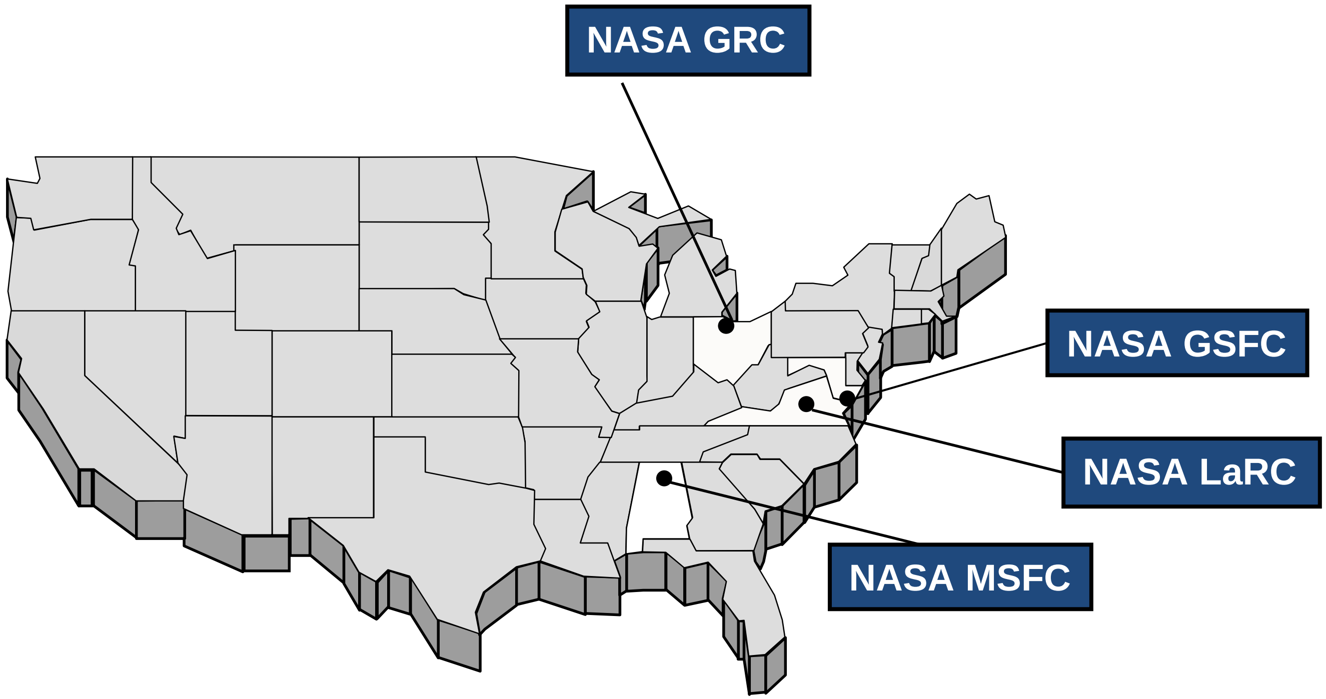
QUANTITATIVE IMPACT

- Provides potential cost savings, weight savings and improved performance with increased reliability compared to metallic structures/joints.
- Demonstrates composite materials, manufacturing, and validated design technologies.
- Reduces risk, lowers lifecycle cost, and enables architectures for future exploration missions.
- Supports SLS composites risk reduction for the Universal Stage Adapter (USA) and the Payload Attach Fitting (PAF).
- Builds on previous work, sustains critical composites competencies, and uses innovative new capabilities at NASA Centers.

TASK GOAL

- Advance composite technologies that provide lightweight structures to support future exploration missions. Focus on the areas of joints and analysis techniques/tools specifically applicable to lightweight composite structures.
- Develop and demonstrate critical composites technologies with a focus on joints and analysis; incorporate materials, design, manufacturing, and tests that utilize NASA expertise and capabilities.
- Mature technologies in cross-cutting areas including materials (alternative fibers), design (tailored laminates, optimized fiber orientation), and manufacturing (in-situ NDE, automation, repeatability)
- Advance analytical approaches that utilize model-based virtual materials, design, and manufacturing.

CTE Organization and Key Members



NASA Center

Academia

Industry